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Highly Integrated Digital Electronic Control "The HIDEDEC Program"



NASA's HIDEDEC F-15 approaches the Edwards AFB runway in 1993 during a Propulsion Control Aircraft (PCA) project development flight. PCA was one of several significant propulsion and flight control integration projects tested and developed on the HIDEDEC aircraft.

NASA Photo EC 93-2081-1

A program called Highly Integrated Digital Electronic Control -- HIDEDEC -- turned NASA Dryden's F-15 research aircraft into a national facility that was used many years for research into the integration of aircraft engine and flight control systems.

The effort to operational link engine and flight control systems was a natural outgrowth of the successful Digital Electronic Engine Control (DEEC) unit flight tested on the F-15 at NASA Dryden between 1981 and 1983. The DEEC program, using a Pratt and Whitney F-100 test engine, demonstrated significant

improvements in thrust, fuel consumption, and engine life. The successful program paved the way for the U.S. Air Force and Pratt and Whitney to install operational DEEC units on all F100 engines powering F-15 and F-16 fighters.

The HIDEDEC project studied the integration of aircraft engine operations with air data and flight control systems to improve aircraft performance. Research efforts led to the development of several control modes that demonstrated extended engine life, increased engine thrust, and lower fuel consumption.

The major elements of HIDEDEC were a Digital Electronic Flight Control System (DEFCS), the engine-mounted DEECs, an on-board general-purpose computer, and an integrated architecture allowing all components to "talk to each other."

Digital systems developed on the HIDEDEC F-15 were the adaptive engine control system (ADECS) and performance seeking control (PSC). It became the first aircraft to demonstrate the self-repairing flight control system (SRFCS) and the propulsion-only flight control system (PCS).

The integration of digital propulsion and flight control systems on military, commercial, and general-purpose aircraft could lead to very significant savings in fuel, maintenance, and operational costs. The advantages of extended engine life and enhanced engine and flight performance also give the aircraft a greater safety margin, a factor that can be appreciated by aircrews as well as passengers.

The HIDEDEC Aircraft

The HIDEDEC F-15 was originally a U.S. Air Force air superiority fighter. NASA used the "A" model, obtained from the U.S. Air Force on Jan. 5, 1976, on more than 25 advanced research projects

involving aerodynamics, performance, propulsion control, systems integration, instrumentation development, human factors, and flight test techniques. Its last flight at NASA Dryden was on Oct. 27, 1993.

The F-15 series of aircraft were designed and built by the McDonnell-Douglas Corporation (now a part of Boeing). The first flight of an F-15 was in 1972. They have a top speed of Mach 2.5 and display excellent transonic maneuverability.

The aircraft has a large shoulder-mounted swept-back wing, twin vertical stabilizers, and large horizontal stabilizers. They are 63.75 feet long and have a wingspan of 42.83 feet.

Two-afterburning turbofan Pratt and Whitney F100-PW-100 or -220 engines normally power F-15s. The HIDEDEC F-15 used advanced versions of the F100 called the F100 EMD (engine model derivative). Both of the engines on the HIDEDEC aircraft were equipped with Digital Electronic Engine Control (DEEC) units in 1983 following the completion of the DEEC test and evaluation project.

For its research role with NASA, most of the aircraft's weapons systems were removed and much of this space was devoted to instrumentation and data collection systems, and experiments associated with specific projects.

The standard F-15 has a mechanical flight control system that provides control of the ailerons, rudders, and stabilizers. An analog electronic control augmentation system (CAS) operates in all three axes.

On the HIDEDEC aircraft, a digital electronic flight control system (DEFCS) augmented the standard flight control system and replaced the analog CAS. It was a dual-channel, fail-safe system that could be programmed in Pascal, Ada, and FORTRAN. It was linked to Military Standard

1553B and standard F-15 (H009) data buses to tie together all other electronic systems, including the aircraft's engine inlet control system to allow integrated inlet cowl and ramp control research.

Integrated Propulsion and Control Projects

Over a span of about 15 years, the HIDECS was used to develop several modes of integrated engine and flight control systems. Each took advantage of the HIDECS's digital electronic flight control system to improve aircraft engine and operational performance, and flight safety.

These integrated modes are Adaptive Digital Engine Control System, Performance Seeking Control, Self-Repairing Flight Control System, and the Propulsion-Only Flight Control System.

Adaptive Engine Control System

The Adaptive Engine Control System (ADECS) improves engine performance in a demanding flight environment by borrowing an engine's excess stall margin through the integrated and computerized flight and engine control systems. An engine's stall margin is the amount that engine-operating pressures must be reduced to supply a margin of safety to prevent an engine stall because of excessive pressure.

ADECS uses airframe and engine data to allow the engine to operate at higher performance levels at times when the inlet distortion is low and the full engine stall margin is not needed. This improves thrust levels by increasing the engine pressure ratio (EPR) at a constant airflow. Fuel consumption also dropped with a reduced throttle setting to hold thrust constant as the EPR was increased. In this mode, the ADECS is basically trading excess stall margin for improved performance.

Initial engineering work on ADECS began in 1983. Research and demonstration flights commenced in 1986.

During the ADECS flight evaluations, the F100 EMD engines displayed thrust improvements of between 8 and 10 percent at various altitudes. Fuel flow reductions of between 7 and 17 percent were recorded at maximum afterburning thrust levels at an altitude of 30,000 feet while holding constant engine thrust.

The increased engine thrust improved the F-15's rate of climb by 14 percent at 40,000 feet, while the aircraft's time-to-climb from 10,000 feet to 40,000 feet dropped 13 percent. Acceleration improvements of between 5 and 24 percent were also recorded at intermediate and maximum power settings at various altitudes.

No engine stalls occurred during any flight scenario, although intentional stalls were produced to validate ADECS methodology.

ADECS technology has been incorporated into the Pratt and Whitney F119 engines used on the new Air Force F-22 advanced fighter.

Performance Seeking Control

The principle of Performance Seeking Control (PSC) was to optimize an aircraft's engine performance during steady-state operations. PSC was essentially a follow-on project of the Adaptive Electronic Control System, which enhanced engine performance in dynamic flight situations.

When the ADECS mode was being developed on the HIDECS aircraft, the flight control computer stored schedules of optimum engine pressure ratios based on an average engine on a normal day. PSC steps up to the next level by integrating control laws to provide the highest engine and maneuvering

performance at all times and in all types of flight environments.

PSC measures many parameters to identify the condition of engine components and optimize them to achieve the best efficiency based on actual engine conditions and flight environment.

PSC flights with the HIDECA aircraft began in 1990. Research data soon revealed that PSC reduced turbine temperatures by more than 160 degrees (F). This reduction of operating temperatures can significantly extend the life of jet engines.

Flight test results also showed that PSC significantly improves thrust at varied flight conditions, including accelerations and climbs. On a refurbished engine, thrust increases of up to 15 percent were achieved, while on a degraded test engine, thrust was improved 9 percent.

Besides improving engine functions, PSC also incorporates the capability to detect engine wear and the impending failure of certain components. Such data, combined with routine preventative maintenance, can help improve the dependability of propulsion systems on many types of aircraft.

Pratt is now using technology from the Performance Seeking Control project, which can be applied to a wide variety of aircraft, and Whitney on the F119 power plant used in the new Air Force F-22 advanced fighter, and in other advanced engines.

Self-Repairing Flight Control System

The Self-Repairing Flight Control System (SRFCS) is a software addition to an aircraft's digital flight control system that detects failures and damage to ailerons, rudders, elevators, and flaps. The system -- which can be used on nearly all aircraft with digital

flight control systems -- then compensates for the component loss by reconfiguring the remaining control surfaces so flight crews can land their aircraft safely. Installed on military aircraft, the unique system would allow aircrews experiencing a control surface failure to complete important tactical missions.

The SRFCS was successfully flight tested on the HIDECA F-15 at NASA Dryden between December 1989 and March 1990. An advanced version of the SRFCS was subsequently tested in 1998 on an unpiloted X-36 research vehicle.

A standout feature of the SRFCS -- also known as the reconfigurable flight control system -- is a cockpit display that presents pilots a visual warning explaining the type of system failure the aircraft has experienced due to a malfunction or combat damage. The readout, which can be presented on a heads-up display, gives pilots new flight limits such as reduced speed and maneuvering limitations that the failure or damage may impose.

The SRFCS includes a maintenance diagnostic capability. Built-in test and sensor data are used to identify failed components or system faults that often are not seen in ground maintenance. This in-flight diagnostic feature identifies intermittent faults that often occur only during high maneuvering loads, or during high hydraulic-flow requirements. Having the ability to identify faults or failures in advance of post-flight inspections eliminates inconclusive ground checks and excessive maintenance hours.

The immediate benefits of the SRFCS would be a reduction of serious incidents and fatal accidents involving failed or damaged flight control systems. But the benefits of the system extend beyond detecting and overcoming these failures.

The diagnostic capabilities of the SRFCS can reduce ground maintenance time for commercial air carriers. The result would be faster and more

efficient service cycles for each aircraft and increased revenue. Easier and faster maintenance diagnostic work also translates into lower maintenance costs and increased operating revenues.

Military forces utilizing the SRFCS on combat and support aircraft would also enjoy reductions in ground maintenance time and expenses, but the greatest benefit to military forces would be a higher aircraft combat readiness rate. Military aircrews would also have a greater chance of completing combat missions following damage to flight control components.

The SRFCS, because of its added safety factor, could also lead to lower insurance costs for owners and operators of commercial and general aviation aircraft.

Propulsion Controlled Aircraft System

The Propulsion Controlled Aircraft System (PCA) was developed and flight tested at NASA Dryden in an effort to help pilots land safely when normal flight control components -- elevators, rudders, and ailerons -- are disabled because of major flight control system failures. PCA uses computer-augmented engine thrust to give flight crews faced with a flight control system failure enough pitch, yaw, and roll authority to fly the aircraft until an airport is reached and a safe landing can be made.

The PCA system was tested and initially demonstrated on the HIDEF F-15. It was later tested and publicly demonstrated on a three-engine MD-11 jetliner. In simulator studies, NASA has also demonstrated the PCA concept on more than a dozen other types of commercial and military aircraft.

In the past three decades, at least 10 aircraft accidents have been caused by major flight control system failures resulting in the loss of more than 1,200 lives.

The NASA effort to develop the PCA concept was triggered by the United Airlines DC-10 accident in 1989 at Sioux City, Iowa. After a malfunction in the jetliner's tail engine knocked out the hydraulic flight control system, pilot Al Haynes and his crew used manual throttle control to keep the aircraft flying and attempt an emergency landing at Sioux City. Although the flight ended in a fiery crash landing, 181 of the 296 persons on board lived through the accident that drew worldwide media attention.

The PCA concept is simple. When activated, the PCA system electronically merges the aircraft's flight control and engine control computers to harness engine thrust and control the aircraft. When the control wheel or stick is pulled back, engine thrust is automatically increased and the aircraft begins to climb. Push the control wheel or stick forward and engine thrust is reduced and descent begins. Turning the wheel -- or moving the stick -- right or left applies differential engine thrust and the aircraft begins to yaw (sideslip) in the direction of the desired turn. Modulating the differential thrust will stabilize the turn once the designated heading is achieved.

Based on the successes of PCA flights with the HIDEF F-15 and the MD-11, NASA considers a PCA system an acceptable backup flight control system capable of controlling an aircraft to a safe landing after a flight control system failure.

Flight tests with the HIDEF F-15 were carried out at speeds of 150 knots with the flaps down, and with the flaps up at speeds between 170 and 190 knots. The tests included control capability in an "up and away" scenario, and landing approaches down to less than 10 feet above the runway.

The HIDEF tests ended with a successful PCA landing on April 21, 1993, when the research pilot used only engine power to turn, climb, and descend to the runway.

Follow-on PCA research and flight demonstrations using the MD-11 transport came in 1995 when it was tested in a variety of flight situations -- mid and aft CGs (centers of gravity), at altitudes that ranged from 200 feet to 30,000 feet, and at speeds from 160 to 360 knots. The system was also successfully tested to simulate many emergency scenarios.

The immediate benefit of a PCA system is having an emergency backup control system to avoid

accidents because of control system failures. But PCA benefits reach beyond this basic safety feature.

The PCA technology was later expanded to produce versions called PCA Lite and PCA Ultralite that incorporate the engines-only control concept for use in a variety of aircraft but at more moderate purchase and installation costs.